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EFFICIENCY OF A MODERN GAS ENGINE

THE EFFICIENCY OF A MODERN GAS ENGINE OF THE WALRATH TYPE

A Thesis submitted

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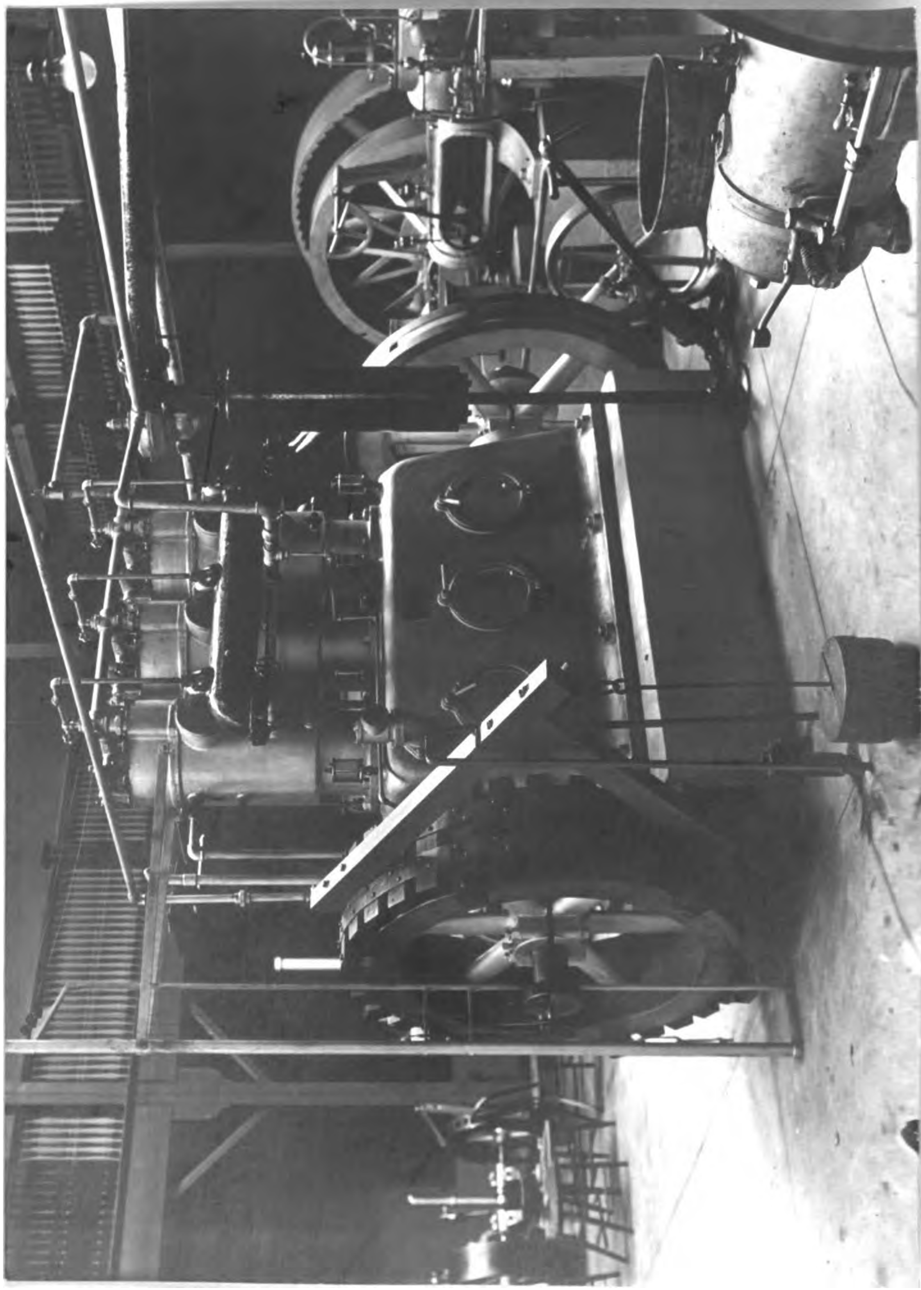
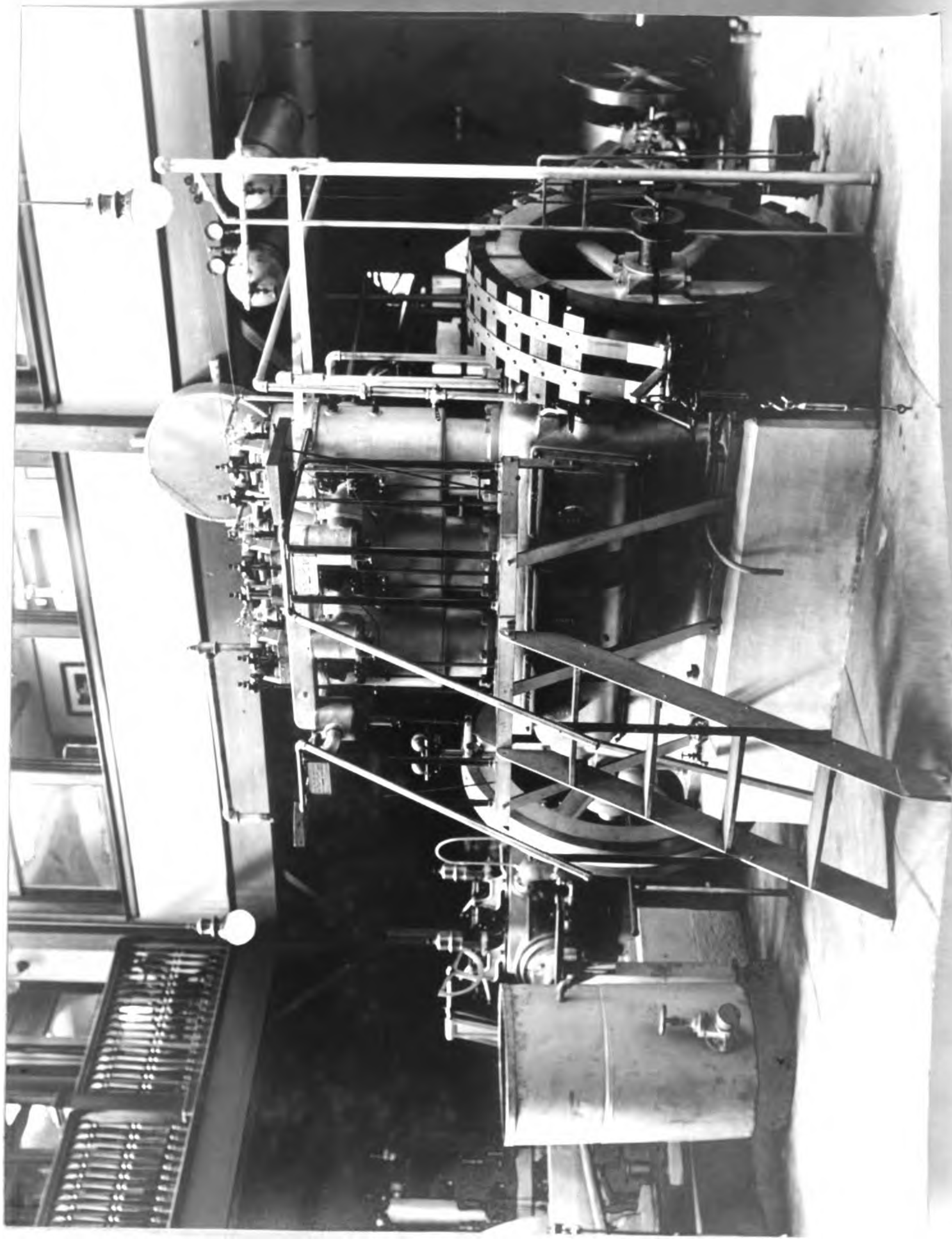




There are at present two competitors of the reciprocating steam engine--the steam turbine and the gas engine.

In the judgment of some, the steam turbine is the coming source of power for central stations, but the greater majority of engineers favor the gas engine.

In considering a gas engine for central station work the following points must be noted:

1. Continuity of service at any cost.

2. Simplicity of operation conducing to the above and securing lew cost of attendance.

3. Reasonable cost of equipment.

4. Economy of fuel and supplies

It will be admitted that at the present time the gas engine is not as reliable as the steam engine. Some think that this is due to the fact that gas engines are not made heavy enough, which is probably true to a certain extent, but the greatest difficulty seems to be found in the variation of the quality of the gas. This is usually shown when a gas engine is working nearly up to its maximum power, and everything is going along smoothly, by having it "lie down" or refuse to carry the load. The above, however,

might also be due to a failure of the igniters.

But gas engines have been run under working conditions for considerable length of time as is shown by the following:

A two cylinder sixty-five horse power, vertical engine in one station ran eight thousand and two hundred thirty hours out of a total of eight thousand four hundred seventy two, or ninety seven per cent of the time. During this period the engine ran without stopping one thousand one hundred fifty seven hours when it was shut down to repair a broken belt. Of the two hundred forty two hours shut down only fifty one might be charged to the engine.

Another case is that of a pumping station in Alleghany, a short distance from Pittsburg, when five eighty five horse power engines operate regularly at full load without stops except on Sundays when the units are shut down in rotation for inspection and repair.

One might also call attention to a one hundred fifteen horse power engine in a central station in England which ran for one hundred thirty eight days and nights without a single stop. During two years it ran ninety six and sixtenth's per cent of the total time. The average thermal efficiency during the two years was twenty five and onetenth per cent, calculated on the indicated horse power

and calorific value of gas used.

It is needless to say that such service as the above would not be required in central stations, as reserve capacity should always be available.

The skill required to operate a gas plant is apparantly no greater than that required for steam plants.

In cost, the gas engine equipment is quite comparable with that of a steam plant. The engine itself would cost more than a steam engine of corresponding size, on account of the increase in metal required for the higher pressures dealt with. But with the cost of condensing machinery, biolers, etc., charged to the steam engine this disparity is much reduced. With natural or illuminating-gas supply available, the equipment cost would fall considerably below that of a steam plant of boilers, engines, condensers, heaters, pumps, etc. In the case of a producer-gas plant installed to supply the gas engines, the cost of the respective equipments, each of one thousand horse power is at a parity, although depending somewhat upon the gas storage capacity provided. This, however, amounts to much less than electric storage.

Considering the increase in productiveness of labor, which is stated by a prominent gas engineer to be fully one hundred per cent, (owing to the fact that one man can handle twice the amount of coal.) the advantage if any held

by the steam plant disappears.

In the economy of fuel the gas engine admittedly has no rival. The present limit of steam engine practice is about ten pounds of water per indicated horse power or eleven pounds per brake horse power. With an evaporation of ten pounds of water per pound of good coal (14000 B.T.U. per pound) a brake horse power may be obtained by the consumption of one and one tenth pounds of coal or fifteen thousand four hundred B. T. U.

The gas engine at the present time delivers at full load a brake horse power upon ten and one-half or eleven cubic feet of gas (of 900 to 1000 B.T.U. per cu. ft. calorific value) which is equivalent to ten thousand or eleven thousand B.T.U. per brake horse power.

At full load the average thermal efficiency of gas engines at the present time might be said to be about twenty five per cent.

Considering the comparatively high limit of gas engine efficiency, and the fact that the theoretical efficiency of a steam engine working between the usual limits of one hundred fifty pounds boiler and three pounds condenser pressure has already been exceeded by the gas engine, there appears to be an encouraging future for the internal combustion engines.

The advantages of the gas engine for central stations might be summarized thus:

1. Minimum fuel and heat consumption.

2. Light load efficiency is higher than that of steam engines of corresponding size.

3. Low cost of operation and maintenance.

4. Small number of auxiliaries required.

5. Simplification of equipment.

6. Absence of stand-by losses.

7. Quick starting.

8. Waste heat in jacket water suitable for building heating.

9. Ease of extending equipment.

10. Absence of high pressure except in engine cylinder. (There is no danger from explosion outside as a misture of proper proportions is required.)

11. Power can be stored during light loads at small cost in the form of gas in the holder.

One of the most important sources of economy in gas plants is the fact that as soon as an engine is shut down all heat losses cease. Also during operation no heat is lost by the gas in transit from the producer.

The gas engine fulfills every requirement for quick starting. The two hundred eighty horse power pumping

units of the Philadelphia high pressure fire system have been repeatedly started cold, brought up to speed and the pumps loaded to the required pressure (300 pounds per square inch) within a period of forty seconds from the starting signal.

A case might also be mentioned of a central station where high speed generators with a frequency of one hundred thirty three are used. The units are regularly started in two minutes, but this may be reduced to one in case of necessity.

The governing of gas engines has been perfected to such an extent that the running of alternators in parallel is being successfully done in several stations.

DESCRIPTION.

THE ENGINE. The engine used in the work of this thesis is the Walrath Gas Engine recently acquired by the Steam Laboratory of the University of Wisconsin from the Marinette Iron Works. While it is not as large as many central station engines, being of seventy five horse power rated capacity, still in every other respect it is a typical central station engine.

It is a three cylinder, vertical, four cycle engine, with cylinders eleven and one half inches in diameter, and has a twelve inch stroke.

The cylinders compress the gas into a space of 277.68 cu. inches, at the same time giving a pressure of about one hundred pounds per square inch.

Both the admission and exhaust valves are located on the top of the cylinders where they are readily accessible. They are worked by rocker arms which receive their motion from cams. The cams are upon an auxiliary shaft which is connected to the main shaft by gearing, and revolves at one half its speed. This auxiliary shaft revolves in the same direction as the main shaft. It carries all the cams; three for exhaust, three admission and three ignition. The governor is also run from this shaft. The exhaust and ad-

mission cams are keyed to the shaft so that their position cannot be changed, but the igniter cams are fastened with set screws. The finer adjustments of the igniters are made by moving the follower back and forth.

GAS SUPPLY. The gas was taken from the four inch main on Langdon Street. There are four inch cross mains on Lake and Francis Streets connecting the Langdon street main with a six inch main on State street.

From the end of the Langdon street main the gas passes through a three hundred light meter situated in the Boiler-house, and then through a two and one half inch pipe up to the Engineering building where the engine is located. Two more meters each of one thousand two hundred cubic feet capacity are placed here, they being connected in parallel ---one not being considered large enough. From the meters the gas goes into the bag and then to the reducer and into the engine.

The gas bag is simply a very shallow metal cylinder of about three and one half feet diameter and six inches deep, over one end of which is placed a heavy rubber head, thus giving it the appearance of a large drum.

The reducer was adjusted so as to reduce the gas to atmospheric prrssure, it being supplied at the Boiler-house at a pressure of from two and one half to three and one half inches of water.

The valve which serves the purpose of governing and mixing, consists of a hollow cup-shaped cylinder around which is fitted a sleeve as shown in figures "1", "2", and "3". If the gas and air are not thoroughly mixed in this chamber (a Fig.3) they still have an additional chance for they must go through the passage "b" before they enter the cylinders. d and d' (Fig,3) are valves by which any one or all cylinders can be shut off from the gas supply.

STARTING. The engine is started by means of compressed air. Cylinder C_1 (Fig.3) is cut off from the gas supply and the exhaust valves of cylinders $C_2$and C_3 are left open so that it will not be necessary to start the engine against the compressions which would otherwise have been formed in them. There is a separate valve and cam which admits the compressed air into cylinder C_1.

After the engine has gained momentum the exhaust valve of one of the cylinders is closed and a mixture of gas and air is admitted. This very quickly begins to act, when the third cylinder is thrown in, thus giving the engine two working cylinders. The compressed air is now cut off,and the first cylinder is started. The only reason that the engine is started one cylinder at a time, so to speak, is due to the fact that very much less air pressure is needed to revolve the engine against the compression in one cylinder than when two cylinders are compressing.

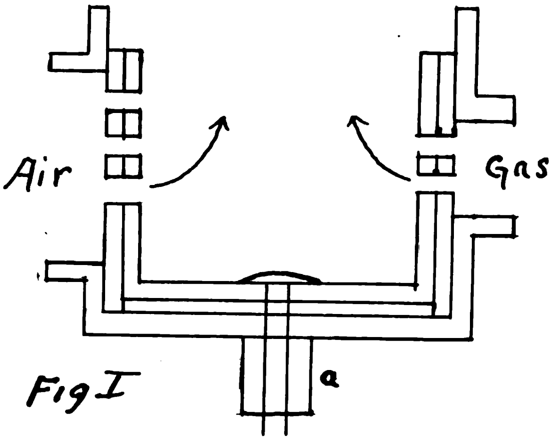


Fig I

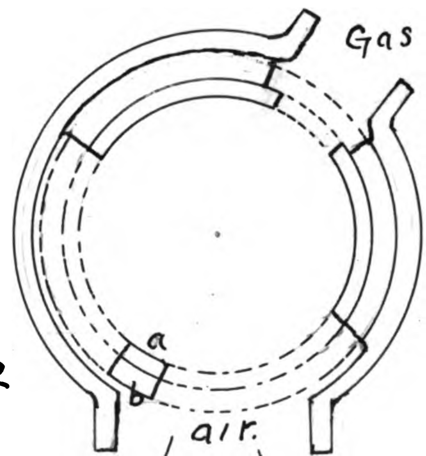


Fig 2

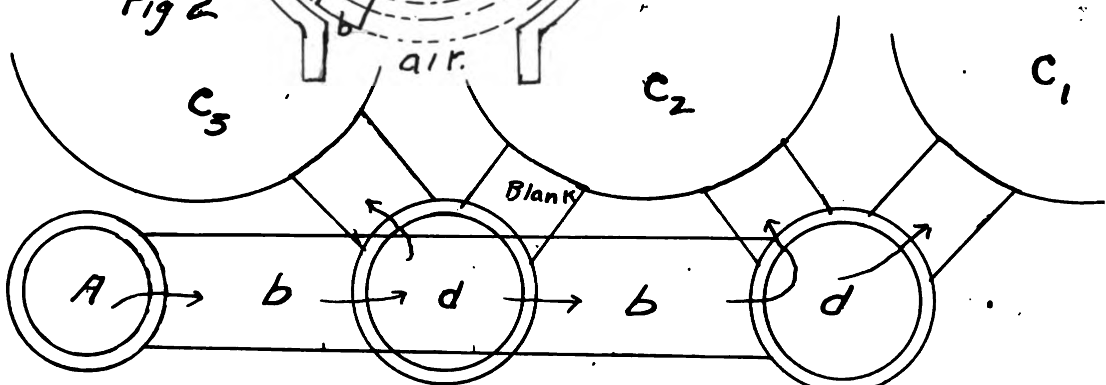


Fig 3

Generally an air pressure of one hundred pounds was used to start the engine, but it has been started on as low a pressure as seventy five pounds.

If the angle of advance of the igniters is large a greater air pressure is necessary than when this angle is small, for if the charge in the cylinder is exploded before the piston has reached the top of the stroke, the engine will be driven backwards, unless the inertia together with the work done by the compressed air is powerful enough to overcome this force. When the igniters had a lead of eighteen or twenty degrees on the cam shaft, which is equivalent to thirty six or forty degrees on the main shaft, at least one hundred pounds of air was required.

THE GOVERNOR. The governor was of the common fly-ball type, When the speed of the engine reached a certain maximum, the balls would spread. This motion was transmitted so that the cylinder in Fig.1 would be raised, thus cutting off both the supply of gas and air. The finer adjustment of speed was accomplished by means of a compression spring just under the mixing chamber, shown at "a" Fig.1.

LUBRICATION. The main bearings were lubricated by oil cups, from which the oil was led to them through tubes. The base of the engine contained about a barrel of oil. As the pistons revolved they would strike in this oil and splash it all over the internal working parts of the engine.

The cylinders were also oiled from this splash.

JACKET WATER. The jacket water was led into the jackets at the top of each cylinder. The three jackets were connected into a common waste pipe through which the water could escape.

From each jacket there also ran a small pipe into the exhaust chamber of the cylinders. The chamber became excessively hot, especially on very heavy loads, and in order to keep the temperature down the exhaust jacket water was used. During light loads almost the entire supply of water was run this way, but on the heavier loads when very much more jacket water was used this was impossible or at least not necessary.

BRAKE. When working under load the power was absorbed by a form of friction dynamometer as shown in the view of the engine. The spring balance was anchored to the floor by means of a hook and adjustable screw. The weights for loading the brake had been cast with slots so that they could be placed on the hook. As a precaution against accidents a bar was thrown over the weight arm in order to prevent the undue lifting of the weights. The teetering motion caused by the variation in friction of the brake was counteracted by a dash-pot placed on the under side of the weight arm.

When absorbing large powers, the rim of the wheel

becomes heated and its undue expansion might lead to fracture. It is therefore cast in the form of a trough ___/ , and cold water is delivered into it. When the wheel is revolving, the water will follow it in the direction of rotation and completely line the trough. A pipe is fixed so as to skim the surface of this water when it reaches a certain depth, and the water so caught is drained away. In this way a conscant circulation is maintained, and the water is kept at a reasonably low temperature.

OBJECT OF THESIS.

The engine was placed in the laboratory during the summer vacation of 1903. The main castings were erected in place and also a small amount of piping had been done at the opening of the school year. It might be said that this thesis consisted primarily in finishing the erection of the engine, getting it into the best possible running conditions, and finally testing it under varying loads.

After the erection was completed short runs were made, in order, to find if possible some way in which the conditions of the engine might be bettered. All kinds of trouble were met with almost constantly. Sometimes a way out of the difficulty would be seen at once, but more often several runs were necessary before the evil was entirely eradicated. Working in this way it was known very nearly what the engine would do even before the final tests were made.

ERECTION.

As has already been said, the main castings were in place and a small amount of piping had been done at the opening of the school year.

The first thing erected was the muffler with its accompanying exhaust and water pipes. The piping for the jacket water and also for the compressed air was now put in, as well as were two steel compression tanks which carried enough air to start the engine. There was a small air pump which could be belted to the main engine whenever so desired and thus renew the air in these tanks, but it has not as yet been used; the compressed air being obtained from the large air compressor which is also located in the steam laboratory.

A two and one half inch gas main ran from the four inch main on Langdon street up to the Engineering building. At the end of this main two meters were connected in parallel, because one was not thought large enough to carry the amount of gas necessary. From the meters the gas was run up to the gas bag, which was fastened to the balcony around the laboratory; and from the gas bag it was led through a two inch pipe through the reducer and to the engine by means of a one and one half inch pipe.

After the above work had been done the oil cups with their necessary piping were put in place. This completed the erection proper; with the engine ready to run after the necessary adjustments had been made.

As it was impossible to judge of the running conditions of the engine without indicaters the work of getting them in order was first taken up.

On the end of the main shaft was fastened a series of three small cranks to which the indicator cords were to be attached. These had to be set so that they worked in exact unison with the piston. As the cylinders were not directly above the main shaft, the highest point reached by the piston was found and the corresponding indicator crank was set so that its maximum height was reached at the same instant.

DIFFICULTIES ENCOUNTERED.

The difficulties encountered might be summarized under the following heads:-

I. Batteries.

II. VaIves.

III. Gas Pressure.

IV. Water.

V. Back Firing.

VI. Angle of Advance of Igniters.

I. Batteries. During all of the runs the ignitors seemed to work perfectly. Their contact points being of iron were sufficiently heated to keep the soot burned off and could always be depended upon to give a good spark if the batteries were strong enough.

The batteries which came with the engine were eight Edison La Lande R.R. cells which were connected in series and discharged through an induction coil. These gave when tested a current of three and one half amperes and a voltage of seven. As these were not thought to be strong enough, twenty Columbia dry cells were obtained and connected up so as to have ten cells in series and the two series sets in parallel. These also had an induction coil. By this arrangement the voltage was raised to fourteen. This change gave

a greater regularity in the running of the engine and also an increase of power over what had been obtained before.

For the rest of the experimenting and also for the tests these dry cells were used and no more trouble was encountered along this line.

II. Valves. The cylinders were supposed to compress the gas to about one hundred pounds per square inch. In one cylinder this amount was nearly obtained, but in another the pressure would not go higher than fifty or sixty pounds. This was after several short runs had been made. This could only be accounted for in one way--there was a leak somewhere. So all of the valves, both the exhaust and inlet valves were taken out and reground. The exhaust valve in the cylinder which would not compress properly was found to be in very poor shape, it touching its seat at only a few points. This regrinding remedied matters so that the maximum brake horse power was raised considerably, the poor cylinder doing a little more than twice the amount of work it had been doing before. An exhaust valve began to leak again during the test and had to be taken out and reground. This time the compression fell to eighty pounds. The cause of the trouble was not the valve itself, but a gummy tar which was formed on it, thus preventing it from

seating properly. This was probably due to too much lubricating oil getting past the piston and pattially burning in the high temperature of the cylinder.

The regulations of the proper proportions of air and gas caused considerable trouble. The valve in the gas pipe regulated the amount of gas obtained, but the amount of air had to remain very nearly constant. The only way this could be changed was by rotating the inner cylinder (Fig. I and II) of the mixing chamber slightly, thus allowing the metal partitions "a"-"b" between the tiers of air slots, which overlapped when the valve was open to spread out; at the same time the length of the slots was furtherdiminished by being cut off at one end. Thus the total length was reduced from about twenty two to nineteen inches. During this time the gas was being shut off also. A very slight rotation would not cut off the gas supply (as shown in the figure) but if this rotation was continued not only would the air be partially shut off, but it was possible to close the gas supply completely.

At first there were two gas openings and four air openings as shown in Figs. I and II. This worked very well on light loads; the gas being less than one-fourth turned on. This mixture was a little weak,but the excess of air was not enough to cause back firing.

During these light runs the governor had the supply very nearly cut off all the time, and the engine ran so smoothly it hardly seemed to be going.

As the loads were gradually increased, more gas had to be turned on, thus increasing the strength of the mixture. The air valve was also varied the little amount possible until it was entirely open. Everything worked well so far, but with the application of further loads the speed of the engine went down. If more gas was turned on, thereby gaining a richer mixture, back firing immediately began, sometimes every few revolutions.

The speed of the engine at times nearly reached the maximum of two hundred fifty while at others, during frequent back firing, it went as low as one hundred seventy five revolutions per minute. The above condition of affairs was carefully noted and tried several times. There was only one cause for this falling off in speed or in this lack of power and that was a lack of air for the heavier loads.

At this time the maximum load obtainable was about thirty one or two horse power. The ignitors were set on the three cylinders with a lead of fourteen and one half, fifteen, and fourteen degrees measured on the cam shaft. After considerable thought and consultation it was decided to cut another air slot in the air valve or mixing chamber,

as shown in Fig. I. With everything else constant the maximum horse power was raised to thirty nine or forty.

Of course in the lighter loads the mixture was very weak and did not give the efficiency that might otherwise have been obtained, yet the engine is not intended to run on light or practically no loads, but is supposed to carry with a fair degree of efficiency brake horse powers varying from twenty five or thirty to fifty five or sixty.

But even with this extra slot, on friction load the mixture was not so weak that it would back fire. The above charge gave the necessary amount of air for the maximum loads obtained later.

III. GAS PRESSURE. What might be said to be the greatest cause of annoyance was the lack of gas pressure. The pressure in the city mains is automatically regulated to four and one half inches at the gas works during the day, and from midnight to six A.M. it is lowered to two and one half inches so as to decrease the amount of leakage.

As city gas was used the pressure obtained at the Boiler house was affected by the gas stoves and lights which began in the afternoon about four or five o'clock and continued to run to a greater or less extent until nine or ten o'clock at night.

The two and one half inch gas pipe which ran from the boiler house up to the steam laboratory and which supplied

the gas used, had about thirty right angled elbows in it, which fact prevented the easy flow of gas and very materially reduced the pressure when the engine was running under heavy loads.

In order to find out if the fall of pressure was due to these bends or not, a maximum load test was made, during which time all the gas which it was possible to get was used--about twelve hundred cubic feet per hour. The pressure at the end of the four inch main at the boiler house averaged before the run at about three and one half inches of water, but during the run it went down to about one and eighty five hundredths. At the Engineering building this was reduced to atmosphere or one tenth inch of vacuum, and when the gas entered the engine there was a vacuum of one to one and one half inches and sometimes as high as one and eight tenths inches. At such a time the gas bag was sucked in instead of being rounded out as it should have been by the internal pressure.

The above results show, however, that the whole fault does not lie entirely with the section of pipe from the boiler house to the Engineering building, but can be charged partially to the four inch city main.

In order to obtain anywhere nearly maximum horse power from the engine, it was necessary to have about two and

three quarters or three inches of pressure at the end of the city main. This made it impossible to run on heavy load tests until after ten o'clock at night.

In making the tests the light loads were run in the evening when the gas pressure was low. The right proportion of air and gas would be given at the start, but as the gas pressure in the mains increased the amount of gas used grew gradually more, or in other words the mixture became richer until back firing occured. Because of this the gas had to be shut off as the pressure rose. Of course the above difficulty would not be encountered in actual central station practice.

In order to partially overcome the above reduction in gas pressure, the one and one half inch pipe which ran from the reducer to the engine was replaced by a two inch pipe.

It might also be said that there will soon be another pipe laid from the boiler house to the Engineering building, connected up in parallel with the one already in. This will very materially raise the pressure at the steam laboratory, making it nearly equal to the pressure at the boiler house even when the engine is running under considerable load.

IV. WATER. In order to obtain the maximum theoretical efficiency of the engine, the jacket water should be kept

as hot as practicable, so as to have the temperature of the cylinders as nearly equal as possible to the temperature of the burning gases. This jacket water temperature should be about one hundred eighty degrees Fahrenheit. It was found impossible to do this. If the cylinders were allowed to become hot, the power immediately fell off usually shown by a lowering of the speed. This was due to the cylinders becoming so hot that the gas was ignited almost as soon as it entered, thus causing a back fire and retarding the engine.

The temperature of the jacket water for light loads was kept at about one hundred degrees Fahrenheit while on heavy loads this was reduced to sixty degrees. The temperature of the jacket water of the three hundred eighty horse power engines of the Madison Gas & Electric Company is kept at about one hundred twenty degrees.

V. BACK FIRING. Back firing as said above might be caused by the cylinder walls and piston becoming so hot that the incoming gas is ignited. This is especially true if there is any projection within the compression space, for it would become very hot and act as a hot tube ignitor would. Back firing might also be due to a too weak or a too rich a mixture of gas and air.

Most of the back fires which occured during the runs made were either due to a too weak or a too rich mixture.

If a heavy load were thrown on the engine a large amount of gas and air were required, but as said above, the gas pressure being often very low, the proper amount of gas could not be obtained, thus rendering the mixture too weak. At these times the beginning of a run would be made with a comparatively low gas pressure. The air and gas valves would be set properly for the conditions then existing. But during the evening the gas pressure would rise, thus giving more gas and increasing the strength of the mixture to such an extent that it would be too rich and back firing would result. (When the pressure was light we would get a partial vacuum at the engine, and when the pressure raised this vacuum was diminished. The reducer lowered the gas pressure to atmospheric, if it had the proper pressure behind it.)

This back firing both with a too rich or a two weak mixture was due to the fact that the rate of burning was slow. In fact, after the supposedly burnt gases had been expelled through the exhaust, all except what would remain in the clearance, and the exhaust valve had been closed and the admission opened, thus admitting a new charge; the old gas was still burning in the clearance and the moment the new supply came in contact with it a back fire occurred. this back firing did no harm except that it worked against the engine, doing negative work when it ought to have been positive. Sometimes the speed would be very materially

reduced.

Three or four times during the tests several back fires would occur in succession and the burning gases being expelled into the mixing chamber, would set the incoming mixture afire, so that it burned as fast as it was formed. At such a time the gas supply would be immediately shut off, thus putting out the flame, after which it would be again admitted and the engine continue running, having missed only a few explosions.

VI. ANGLE OF ADVANCE OF IGNITERS. The ignition points on the three cylinders at first were set at seven, nine, and four degrees advance measured on the cam shaft. With these angles of advance the most it was possible to get out of the engine was about fifteen horse power. The igniter cams were then set ahead so that they were at ten, ten and one half, and eleven degrees, numbering from the right cylinder. This very materially increased the maximum load which could be obtained. The lead angle was again raised to fourteen and one half, fifteen, and fourteen degrees and then to twenty, twenty,and eighteen degrees at which angles the tests were run. The third cylinder ignited a little later than the other two for the reason that the engine started so much more easily when the angle of advance was not very large. With this angle eighteen

degrees, or thirty six on the main shaft, it was necessary to use one hundred pounds of air pressure, and let the engine gain quite a momentum before the exhaust valve on another cylinder could be closed, or the engine would tend to go backwards, due to the fact that the explosion came before the top of the stroke was reached.

After the tests were made the ignitors were set further ahead, to twenty one and one half, twenty two and one half, and twenty and one half degrees, and a short run was made. These angles were found however to be greater than they should be in order to obtain the best results.

At one time the engine was started on the cylinder that had the ignitor angle of advance of twenty two and one half degrees, but it required one hundred and twenty pounds of air to do so.

If the engine was run at full speed, two hundred fifty revolutions per minute, an angle of advance of nineteen or twenty degrees gave the best results, but if the speed was lowered for any reason there was considerable pounding due to the too early explosions. This pounding also occurred even at full speed on a lead of twenty two and one half degrees. In some cases it was heavy enough to cause a perceptible wobbling of the end of the shaft.

INDICATOR CARDS.

As the engine was gradually put into condition, cards were taken to aid in discovering the various causes of trouble.

Card "1" is a card taken at the beginning of the work and shows that the ignition was too late as well as that the mixture burned too slowly, due to a weak spark and poor mixture. In fact the explosion did not get in its work until the piston had started to return.

Card "2" is an improvement, but still the mixture is not what it ought to be. The poor mixture in nearly all of these tests was due to a lack of gas pressure, thus making the amount of air a great deal more than the amount of gas which could be obtained, required. This is shown very nicely in card "6", for at the time this card was taken the engine was pulling the gas until there was about half an inch of vacuum in the gas pipe at the engine when there ought to have been armospheric pressure.

Before card "3" was taken a stronger battery was put in, so that part of the improvement here was due to the battery as well as to the greater angle of advance.

As the angle of advance was increased up to twenty degrees, the cards continued to improve, or in other words

the engine did more and better work.

Card "4" is a good card but the explosion line slopes too much to the right.

In card "5" this line still slopes to the right a little but not enough to materially reduce the amount of work done. This is as nearly an ideal card as we obtained.

Card "6" is also good, being similar to "5".

In card "7" the explosion came too early as shown by the explosion line sloping to the left. This made the maximum pressure come upon the piston when the crank was on dead center, or even before it got to dead center, thus wasting the power by expending it in bending the shaft, or even in tending to drive the engine backwards.

Card "8" was made, to see if there was any vacuum in the cylinder at admission, or in other words if the admission ports were large enough. No vacuum is decernable on this card.

Card "9" shows a charge which was ignited during the compression, thus raising the maximum pressure to three hundred fifty pounds when it ought to have gone only to two hundred sixty. Of course this charge did a great deal of negative work, so much in fact that it nearly compensated for all the positive work which it did.

Card "10" shows a card taken just before one of the exhaust valves was ground. This gives a compression of

eighty pounds when it ought to have been at least one hundred pounds.

Card "11" shows the effect of the inertia of the moving parts of the indicators if they are not properly adjusted, or if the spring is too sensative.

THE TESTS.

Six runs were made with the brake loads varying from zero to fifty one and four tenths horse power. The time of each run was two hours.

As has already been said, on account of the lack of gas pressure the tests were made at night after most of the gas stoves and lights had been turned off.

Indicator cards were taken every ten minutes as well as were the various temperatures, pressures, and speed readings.

The angle of advance remained at twenty, twenty, and eighteen degrees for all the tests. Some of the jacket water was sent through the exhaust so as to keep its temperature down. A small amount of this was evaporated by the hot gases but it did not amount to more than three or four percent of the total amount of water used. This water and also the water which came from the jacket direct was weighed.

Temperatures of the gas, and atmospheric pressures were taken in order that the gas might be reduced to standard temperature and pressure.

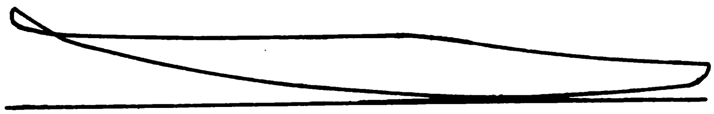
The B.T.U. of the gas was also taken. As the Junkers

calorimeter was out of order at the time the runs were made the B.T.U. was not determined until the day after the last test. The gas used was taken from what remained in the gas pipe which ran from the boiler house up to the Engineering building. In this way the same quality of gas was obtained as had been used in the previous run.

Samples of exhaust gases were tested during the different runs in order to find the amount of CO, CO_2, and O present.

The gas meters at the Engineering building were read, but the amount of gas used was obtained from the large meter in the boiler house which was thought to be more accurate.

Card #1.



Angle of advance 4°. Spring 200#. M.E.P. 38.5#.

Card #2.

Angle of advance 9°. Spring 320#. M.E.P. 71.2#.

Card #3.

Angle of advance 12.5°. Spring 320#. M.E.P. 73.6#.

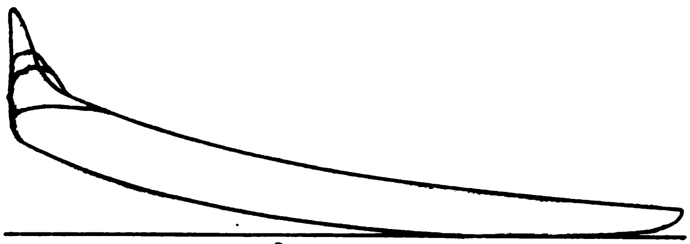
Card #4.

Angle of advance 15°. Spring 320#. M.E.P. 80#.

Card #5.

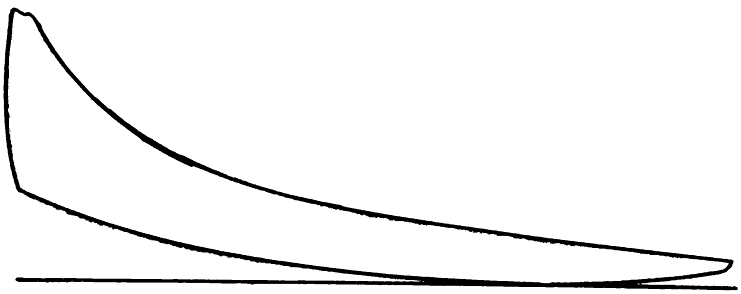
Angle of advance 20°. Spring 320#. M.E.P. 82.7#.

Card #6.



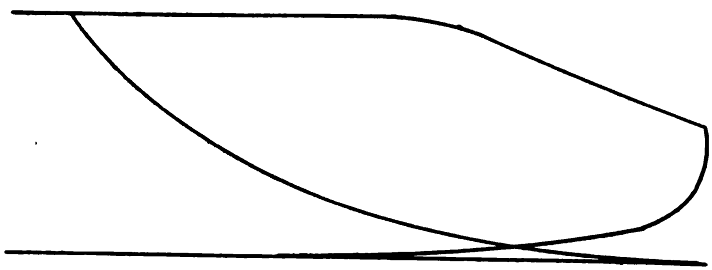
Angle of advance 21.5°. Spring 200#. M.E.P. 60#.

Card #7.



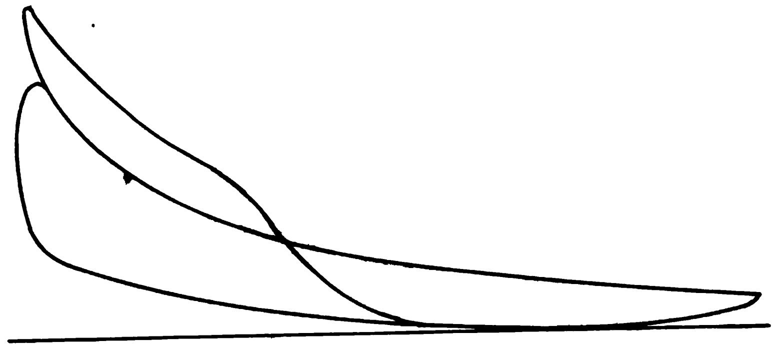
Angle of advance 22.5°. Spring 200#. M.E.P. 72#.

Card #8.



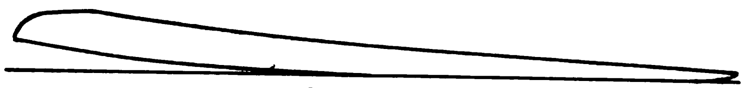
Spring 50#.

Card #9.



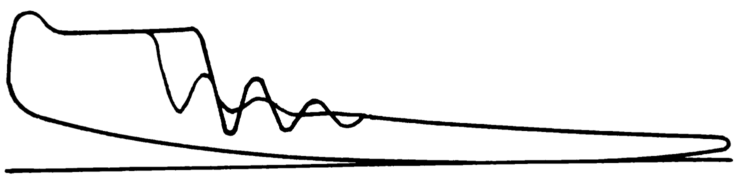
Angle of advance 22.5°. Spring 200#. M.E.P. 70#.

Card #10.



Angle of advance 12.5°. Spring 320#. M.E.P. 46#.

Card #11.



Angle of advance 20.5°. Spring 320#. M.E.P. 88#.

TEST

HORSE POWER

Mch.5,1904.	Cylinder I.		Cylinder II.	
Time,p.m.	M.E.P.	I.H.P.	M.E.P.	I.H.P.
2:40	7.98	3.21	20.00	8.04
2:50	7.68	3.08	20.4	8.2
3:00	7.8	3.08	21.48	8.47
3:10	8.01	3.20	19.02	7.60
3:20	9.9	3.9	20.00	7.87
3:30	9.	3.54	19.02	7.50
3:40	7.95	3.14	23.49	9.26
3:50	9.75	3.87	18.96	7.6
4:00	9.3	3.62	18.15	7.05
4:10	10.8	4.26	20.00	7.9
4:20	10.29	4.18	18.51	7.53
4:30	9.45	3.72	22.95	8.05
4:40	7.98	3.2	20.4	8.16
Average	8.75	3.54	20.17	7.94

NO. I.

AND EFFICIENCY LOG

Engine Constant .001572

Cylinder III. M.E.P.	I.H.P.	Total I.H.P.	B.H.P.	R.P.M.
7.5	3.07	14.42	0	255
4.5	1.81	13.09	0	255
6.00	2.36	13.81	0	251
4.5	1.9	12.70	0	254
9.00	3.54	15.31	0	250
9.00	3.54	14.58	0	250
7.5	2.96	15.36	0	251
7.5	3.00	14.47	0	252
7.5	2.92	13.59	0	247
6.0	2.36	14.52	0	251
4.8	1.95	13.66	0	258
6.75	2.66	14.43	0	251
5.01	2.00	13.38	0	252
6.58	2.62	14.1	0	252

TEST

HORSE POWER

Mch.11,1904.	Cylinder I		Cylinder II	
Time,p.m.	M.E.P.	I.H.P.	M.E.P.	I.H.P.
8:00	29.28	11.55	26.40	10.40
8:10	27.2	10.80	32.00	12.70
8:20	30.4	11.95	37.20	14.60
8:30	33.6	13.25	34.40	13.60
8:40	32.8	12.90	33.20	13.00
8:50	34.64	13.60	32.48	12.90
9:00	34.4	13.50	36.00	14.10
9:10	37.20	14.80	40.00	15.90
9.20	36.00	14.20	32.00	12.60
9:30	34.64	13.67	34.40	13.55
9:40	34.00	13.40	34.40	13.55
9:50	32.80	12.90	34.40	13.50
10:00	36.8	14.50	37.28	14.70
Average	33.36	13.07	34.16	13.35

NO. II.

AND EFFICIENCY LOG

Cylinder III M.E.P.	Cylinder III I.H.P.	Total I.H.P.	B.H.P.	R.P.M.	Mech. Eff.
16.	6.31	28.26	9.55	251	33.7
16.	6.36	28.86	9.6	252	32
16.8	6.61	33.16	10	250	30.2
16.	6.31	33.16	10.3	251	31.4
16.	6.30	32.20	10.25	250	32.00
16.8	6.68	33.38	14.2	253	42.6
24.00	9.40	37.00	13.75	249	37.2
12.00	4.78	35.48	14.2	253	40
24.00	9.50	35.30	13.82	251	39.2
20.8	8.20	35.42	13.35	251	37.7
21.3	8.40	35.32	13.05	251	37.00
21.3	8.40	36.80	13.00	250	35.4
14.4	5.68	34.90	13.05	251	37.3
18.1	7.12	33.48	12.2	251	36.4

TEST

HORSE POWER

Mch.12,1904	Cylinder I.		Cylinder II.	
Time,p.m.	M.E.P.	I.H.P.	M.E.P.	I.H.P.
8:00	40.	14.65	36.00	13.18
8:10	45.6	18.00	40.00	15.80
8:20	45.8	18.00	43.20	17.00
8:30	41.84	16.45	40.00	15.70
8:40	47.2	18.50	37.28	14.65
8:50	41.6	16.45	40.80	16.25
9:00	44.0	77.26	40.80	16.05
9:10	42.4	16.65	44.00	17.26
9:20	42.4	16.05	42.64	16.75
9:30	43.2	17.00	42.64	16.75
9:30	41.6	16.35	40.00	15.70
9:50	41.6	16.35	38.40	15.10
10:00	40.0	15.70	44.20	17.30
Average	43.4	16.77	40.84	15.58

NO. III.

AND EFFICIENCY LOG

Cylinder III M.E.P.	Cylinder III I.H.P.	Total I.H.P.	B.H.P.	R.P.M.	Mech. Eff.
40.	14.65	42.48	22.7	233	43.5
36.	14.20	47.0	23.4	249	49.7
40.	15.70	50.7	23.4	250	46.
28.	11.	43.15	23.3	250	54.1
29.60	11.60	44.75	23.3	250	52.1
26.64	10.55	43.2	23.	252	53.25
33.	12.95	46.26	23.3	250	50.4
29.60	11.75	45.66	23.3	250	51.
32.	12.67	46.	23.3	250	50.7
24.	9.45	43.2	23.3	250	54
24.	9.45	41.5	23.27	250	56
31.20	12.25	43.7	23.35	250	53.3
30.64	12.	45.	23.3	250	51.8
31.12	12.45	44.80	23.25	250	51.5

TEST

HORSE POWER

Mch.11,1904 Time,p.m.	Cylinder I. M.E.P.	I.H.P.	Cylinder II M.E.P.	I.H.P.
10:00	48.00	19.00	42.64	16.8
10:10	50.40	20.00	45.28	17.92
10:20	46.64	18.40	48.00	19.00
10:30	48.00	19.00	48.80	19.25
10:40	47.20	18.65	45.60	18.00
10:50	47.20	18.60	46.40	18.25
11:00	42.64	16.85	48.00	19.00
11:10	44.00	17.35	52.20	20.6
11:20	46.88	18.40	48.00	18.9
11:30	46.72	18.40	50.40	19.8
11:40	46:40	18.20	50.56	19.9
11:50	46.64	18.70	50.56	19.9
12:00	47:00	18.50	46.64	18.3
Average	46.75	18.43	47.93	19.09

NO. IV.

AND EFFICIENCY LOG

Cylinder III M.E.P.	I.H.P.	Total I.H.P.	B.H.P.	R.P.M.	Mech. Eff.
41.04	16.2	52.	31.4	251	60.5
36.24	14.35	52.27	30.75	252	59.5
45.28	17.9	55.3	30.9	251	56
44.24	17.5	56.	31.2	251	55.8
44.80	17.7	54.35	31.2	251	57.5
44.80	17.6	54.45	31.3	250	57.5
44.80	17.75	53.6	31.5	252	58.2
36.00	14.2	52.15	31.4	251	60.
32.00	12.6	50.	31.1	250	62.2
42.40	16.65	54.85	31.3	250	57.1
30.40	12.	50.1	31.3	250	62.5
32.00	12.6	50.8	31.1	250	61.5
40.00	15.7	52.3	31.1	250	60.
39.54	15.42	52.94	31.21	251	59.

TEST

HORSE POWER

Mch.13,1904 Time, a.m.	Cylinder I. M.E.P.	I.H.P.	Cylinder II. M.E.P.	I.H.P.
12:00	60.	23.3	56.	21.75
12:10	58.64	22.8	56.	21.75
12.20	61.28	23.8	59.2	23.10
12:30	60.00	23.3	60.8	23.60
12:40	62.64	24.35	62.64	24.35
12:50	62:80	24:6	56.	21.95
1:10	61.28	23.8	56.	21.75
1:10	58.64	22.7	60.	23.20
1:20	61.28	23.9	64.	25.00
1:30	66.40	26.	60.	23.50
1:40	60.80	23.6	61.2	23.80
1:50	58.64	22.8	60.	23.30
2:00	66.40	25.75	61.2	23.80
Average	61.55	23.9	59.46	23.13

NO. V.

AND EFFICIENCY LOG

Cylinder III. M.E.P.	I.H.P.	Total I.H.P.	B.H.P.	R.P.M.	Mech. Eff.
46.	16.7	55.55	42	230	75.7
44.24	16.55	57.3	43.5	238	76.
44.8	17.4	58.25	45	247	77.2
40.	15.7	60.95	45	250	74.
47.2	18.4	58.87	45	248	76.3
47.2	18.55	61.95	45	250	72.7
4.96	19.5	61.50	45	252	73.2
50.64	19.9	63.4	45	250	71.
48.	18.7	61.4	45	248	73.7
46.4	18.2	61.75	45	250	73.
45.28	17.8	59.7	45	250	75.
45.6	17.9	59.6	45	250	75.
49.8	16.05	58.6	45	250	76.7
45.83	17.75	60	44.6	247	74.5

TEST

HORSE POWER

Mch.12, 1904 Time, p.m.	Cylinder I. M.E.P.	I.H.P.	Cylinder II. M.E.P.	I.H.P.
10:00	55.22	20.00	50.64	18.85
10:10	56.00	21.00	52.80	19.75
10:20	54.64	21.25	50.40	19.60
10:30	60.80	23.90	54.40	21.35
10:40	58.64	22.82	50.64	19.75
10:50	58.64	23.00	52.00	20.40
11:00	53.36	20.95	53.60	21.05
11:10	54.64	21.50	56.00	22.00
11:20	57.60	22.45	53.04	20.65
11:30	57.84	22.70	53.10	20.85
11:40	57.04	22.40	49.60	19.60
11:50	53.36	20.90	53.04	20.80
12:00	58.40	22.90	50.00	19.65
Average	56.63	21.92	52.25	20.33

NO.VI.

AND EFFICIENCY LOG

Cylinder M. E. P.	III. I.H.P.	Total I.H.P.	B.H.P.	R.P.M.	Mech. Eff.
42.4	16.45	62.40	51.4	247	83.7
47.2	18.3	62.85	51.4	247	81.8
46.8	18.15	64.95	51.4	247	79.2
52.0	20.2	67.00	51.4	247	76.8
48.	18.6	67.3	51.0	247	75.8
44.	17.2	63.75	51.6	250	81.
45.36	17.6	63.15	51.	247	80.9
42.4	16.4	65.3	50.6	246	78.2
46.4	18.1	67.	51.2	248	76.5
44.8	17.55	67.	51.5	249	77.
48.	18.6	66	51.8	247	78.5
48.	18.6	64.7	51.8	247	80
45.6	17.7	67.25	51.8	247	77.2
46.16	18.25	65.28	51.4	247	78.7

TEST

PRESSURE -

Mch.5,1904. Time. P.M.	Temperature Jacket water(in)	Jacket water(out)	Exhaust	in Exhaust water.
2:40	54	98	156	140
2:50	50	99.7	183	138
3:00	50	100.7	180	132
3:10	50	99.7	177	138
3:20	52.5	100.2	146	139
3:30	52	100	146	139
3:40	53	100.6	150	140
3:50	52	97.5	151	139
4:00	53	97	154	140
4:10	52	96.5	154	141
4:20	52	95.5	150	141
4:30	52	96	147	140
4:40	52	95	145	140
Average	52	98.2	158.5	139

NO. I.

TEMPERATURE LOG.

Barometer, 29.175

Degrees F.		Pressure.	
Gas	Room	Gasmeter E.B.	Mixing chamber.
96	77	1.3	.2
94	73	1.3	.2
94	72	1.55	.2
94	71	1.3	.2
93	76	1.35	.2
94	77	1.35	.2
94	76	1.35	.15
94.5	76	1.50	.2
95	76	1.70	.15
95	76	1.65	.15
95	74.5	1.75	.15
94.5	74	1.50	.15
94	74	1.50	.15
94.4	74.8	1.47	.185

TEST

PRESSURE -

Mch.5,1904. Time p.m.	Jacket Water In	Out	Temperature Exhaust	Exhaust Water	in Gas
8:00	41	77	129	121	80
8:10	44	74	126	118	81
8:20	44	82	130	123	82
8:30	44	83	130	124	81
8:40	44	82	130	122	80
8:60	45	84	131	124	79
9:00	44	84	130	125	78
9:10	44	84	130	124	77
9:20	44	84	130	124	76
9:30	45	83	130	124	75
9:40	45	84	130	122	75
9:50	45	84	129	124	76
10:00	45	83	131	125	77
Average	44	82.15	130	123	78

NO. II.

TEMPERATURE LOG.

Barometer, 29.175".

Degrees F.	Pressure			Load in lbs.	
			Gas at	On	On
Room	Meter	Engine	Boiler H.	Scale	Arm
70	.95	.1	1.9	15	31.5
70	.95	.1	1.95	15	31.5
70	.95	.1	1.90	12	31.5
70	.95	.1	2.00	10	31.5
70	1.00	.1	1.9	10	31.5
70	.95	.1	1.85	3	48.75
70	.90	.00	2.00	5	48.75
70	1.00	.1	2.05	3	48.75
69	1.1	.1	2.10	5	48.75
67	1.15	.1	2.25	8	48.75
69	1.25	.1	2.35	10	48.75
69.5	1.30	.1	2.45	10	48.75
70	1.30	.1	2.4	10	48.75
70	1.6	.1	2.085	9	42.15

TEST

PRESSURE -

Mch.12,1904. Time p.m.	Jacket Water In	Jacket Water Out	Temperature in Exhaust	Temperature in Exhaust Water	Temperature in Gas
8:00	41.	80	138	130	84
8:10	44.	74	130	126	87
8:20	44	82	132	129	90
8:30	44	80	132	128	92
8:40	44	83	130	126	92
8:50	45	84	130	126	94
9:00	47	82	131	128	95
9:10	46	85	131	128	96
9:20	43	84	129	125	96
9:30	46	83	127	124	96
9:40	47	82	127	124	96
9:50	47	83	128	124	97
10:00	47	78	133	129	96
Average	45	81.5	130.6	126.6	93.3

NO. III.

TEMPERATURE LOG.

Barometer. 29.226".

Degrees F. Room	Pressure Meter	Pressure Gas at Engine	Pressure Gas at Boiler H.	Load in lbs. On Scale	Load in lbs. On Arm.
73	.05	-.5	1.5	28	103
72	.05	-.1	1.65	30	"
72	.30	00	1.65	30	"
72	.40	00	1.75	27	"
71	.40	00	1.75	27	"
71	.35	00	1.78	25	"
71	.40	.1	1.75	27	"
71	.35	00	1.75	27	"
71	.35	-.1	1.75	27	"
72	.25	-.1	1.65	27	"
73	.40	00	1.75	29	"
74	.50	00	1.86	30	"
75	.35	00	1.80	27	"
72.16	.36	-.1	1.72	27	"

TEST

PRESSURE -

Mch.11,1904 Time p.m.	Temperature in Jacket Water In	Out	Exhaust	Exhaust Water	Gas
10:00	45	83	131	125	77
10:10	45	89	142	129	80
10:20	45	90	142	131	81
10:30	45	91	143	140	83
10:40	45	95	144	138	83
10:50	45	98	146	143	83
11:00	45	81	137	134	84
11:10	44	81	134	132	85
11:20	44	82	134	132	85
11:30	44	82	138	134	85
11:40	44	82	139	134	85
11:50	44	82	134	129	85
12:00	44	81	131	127	84
Average	44.5	86	138	132	84

NO. IV.

TEMPERATURE LOG.

Degrees F. Room	Meter	Pressure Gas at Engine	Pressure Gas at Boiler H.	Load in lbs. On Scale	Load in lbs. On Arm.
70	1.30	.1	2.40	48	151
70	1.00	.2	2.40	53	"
70	.95	.2	2.35	53	"
71	1.00	.1	2.50	50	"
70	.95	.2	2.45	50	"
72	.95	.1	2.40	48	"
72	1.30	.15	2.80	48	"
72	1.35	.1	2.85	48	"
71	1.45	.15	2.90	50	"
67	1.40	.15	2.95	48	"
67	1.40	.15	3.00	48	"
71	1.50	.10	3.00	55	"
69	1.40	.10	3.05	50	"
70	1.19	.15	2.70	49.5	"

TEST

PRESSURE -

Mch.12,1904.	Temperature in				
	Jacket Water			Exhaust	
Time	In	Out	Exhaust	Water	Gas
10:00	47	78	133	129	96
10:10	46	59	137	135	96
10:20	47	60	141	138	98
10:30	48	64	146	142	99
10:40	47	63	151	146	98
10:50	43	60	140	139	96
11:00	55	68	142	140	95
11:10	48	63	140	137	93
11:20	46	62	141	139	91
11:30	46	61	140	138	88
11:40	41	60	140	138	85
11:50	41	61	141	139	86
12:00	41	69	138	136	86
Average	45	65.15	141	138.5	93

NO. V.

TEMPERATURE LOG.

Degrees F.	Pressure			Load in lbs.	
	Meter	Gas at		On	On
Room		Engine	Boiler H.	Scale	Arm.
75	-.1	-.75	1.50	80	224
76	-.05	-.65	1.65	83	"
77	00	-.70	1.90	83	"
76	.28	-.3	2.05	85	"
76	.28	-.5	2.20	85	"
76	.25	-.5	2.20	85	"
76	.40	-.3	2.30	85	"
76	.45	-.3	2.40	85	"
75	.35	-.4	2.30	85	"
74	.50	-.3	2.40	85	"
74	.55	-.1	2.45	85	"
73	.60	-.1	2.60	85	"
73	.70	-.1	2.60	85	"
75	.436	-.4	2.42	84	"

TEST

PRESSURE -

Mch.13,1904. Time a.m.	Temperature in Jacket Water In	Out	Exhaust	Exhaust Water	Gas
12:00	41	59	144	141	82
12:10	41	58	150	146	82
12:20	41	58	154	149	82
12:30	41	57	152	148	82
12:40	41	58	167	140	83
12:50	42	59	156	149	84
1:00	41	58	153	149	84
1:10	41	58	142	140	84
1:20	41	57	143	140	84
1:30	41	57	143	140	84
1:40	41	57	148	142	84
1:50	41	57	143	140	83
2:00	41	57	144	141	82
Average	41	57.7	149	143.5	83

NO. VI.

TEMPERATURE LOG.

Degrees F. Room	Pressure Meter	Pressure Gas at Engine	Pressure Gas at Boiler H.	Load in lbs. On Scale	Load in lbs. On Arm.
70	.45	-.3	2.6	93	273
71	.55	-.3	2.7	105	"
71	.60	-.2	2.75	103	"
70	.60	-.2	2.70	103	"
71	.65	-.1	2.75	103	"
71	.60	-.2	2.75	105	"
70.5	.65	-.2	2.8	105	"
70	.60	-.2	2.75	105	"
70	.65	-.25	2.75	105	"
70	.70	-.1	2.80	105	"
70	.75	00	2.85	100	"
70	.80	-.1	2.90	100	"
67	.75	-.1	2.85	100	"
70	.64	-.2	2.765	102.5	"

LOG OF JACKET AND EXHAUST WATER.

TEST NO. I.

Jacket Water	Exhaust Water		
801 #	100	100	100
543.25#	103	100	100
1344.25#	100	100	100
	102	100	100
	100	100	100
	100	100	100
	100	100	100
	100	100	100
	100	100	100
	100	100	100
	100	100	115
	100	100	
	100	100	

3718 #

TEST NO. II.

Jacket Water	Exhaust Water					
642#	100	100	100	100	100	
	100	100	100	100	100	
	100	100	100	100	100	
	100	100	100	100	100	
	100	100	100	100	100	
	100	100	100	100	100	
	100	100	100	100	47	
	100	100	100	100		7047#
	100	100	100	100		
	100	100	100	100		
	100	100	100	100		
	100	100	100	100		
	100	100	100	100		
	100	100	100	100		
	100	100	100	100		
	100	100	100	100		

TEST NO. III.

Jacket Water	Exhaust Water				
523#	100	100	100	100	100
	100	100	100	100	100
	100	100	100	100	100
	100	100	100	100	100
	100	100	100	100	100
	100	100	100	100	100
	100	100	100	100	100
	100	100	100	100	75
	100	100	100	100	7575#
	100	100	100	100	
	100	100	100	100	
	100	100	100	100	
	100	100	100	100	
	100	100	100	100	
	100	100	100	100	
	100	100	100	100	
	100	100	100	100	

TEST NO. IV.

Jacket Water				Exhaust Water	
800		100	100	100	100
700		100	100	100	100
866		100	100	100	100
118		100	100	100	100
	2484#	100	100	100	100
		100	100	100	100
		100	100	100	100
		100	100	100	100
		100	100	100	100
		100	100	100	100
		100	100	100	100
		100	100	100	100
		100	100	100	100
		100	100	100	100
		100	100	100	100

6000#

TEST NO. V.

Jacket Water

755	903	
900	900	
900	904	
910	912	
900	903	
912	904	
900	904	
907	902	
900	900	
911	898	
905	913	
904	909	
906	865	
907		24439#

Exhaust Water

100	100	100	
100	52	100	
100	100	100	
100	100	100	
100	100	100	
100	100	100	
100	100	100	
100	100	100	
100	100	100	
100	100	100	
100	100	70	
100	100		3422#

TEST NO. VI.

Jacket Water			Exhaust Water		
899	910		100	100	
919	921		100	100	
900	970		100	100	
907	934		100	100	
996	998		100	100	
945	895		100	100	
900	910		100	100	
922	921		100	100	
912	911		100	100	
909	1005		100	100	
920	903		100	100	
907	545		100	100	
900		24557#	100	100	
921			100	84	
919					2784#

LOG OF EXHAUST GAS ANALYSIS

TEST NO. I.

March 5, 1904.

Time	CO_2	CO	O
2:45	6.2	.6	9
3:40	5.6	.6	8.8
4:10	5	.5	9
4:35	4	.5	7.6
Average	5.16	8.6 ?	8.6

TEST NO. II.

March 11, 1904.

8:00 P.M.	6.	.4	11
8:40	7.	.2	9
9:10	6.7	.4	8.3
9:35	6.4	.4	8.2
Average	6.5	.35	9.1

TEST NO. III.

March 12, 1904.

8:15	5.6	.3	7.9
8.40	6.	.2	8.
9:10	6.	.1	7.4
Average	5.85	.2	7.76

TEST NO. IV.

March 11, 1904.

Time	CO_2	CO	O
10:05	5.8	.1	8.2
10:30	6.5	.1	8.4
11:00	6.4	.1	8.7
11.30	6.2	.1	6.8
Average	6.2	.1	8.

TEST NO. V.

March 12, 1904.

10:00	6.2	trace	9.
11:00	6.2	"	9.2
11:30	7.	"	8.
Average	6. 46	"	8.75

TEST NO. VI.

March 13, 1904.

12:35	8.	.5	8.4
1:05	6.9	.2	7.
1:30	6:8	.1	8.2
2:05	6.9	0	8.1
Average	7.15	.2	8.

SUMMARY

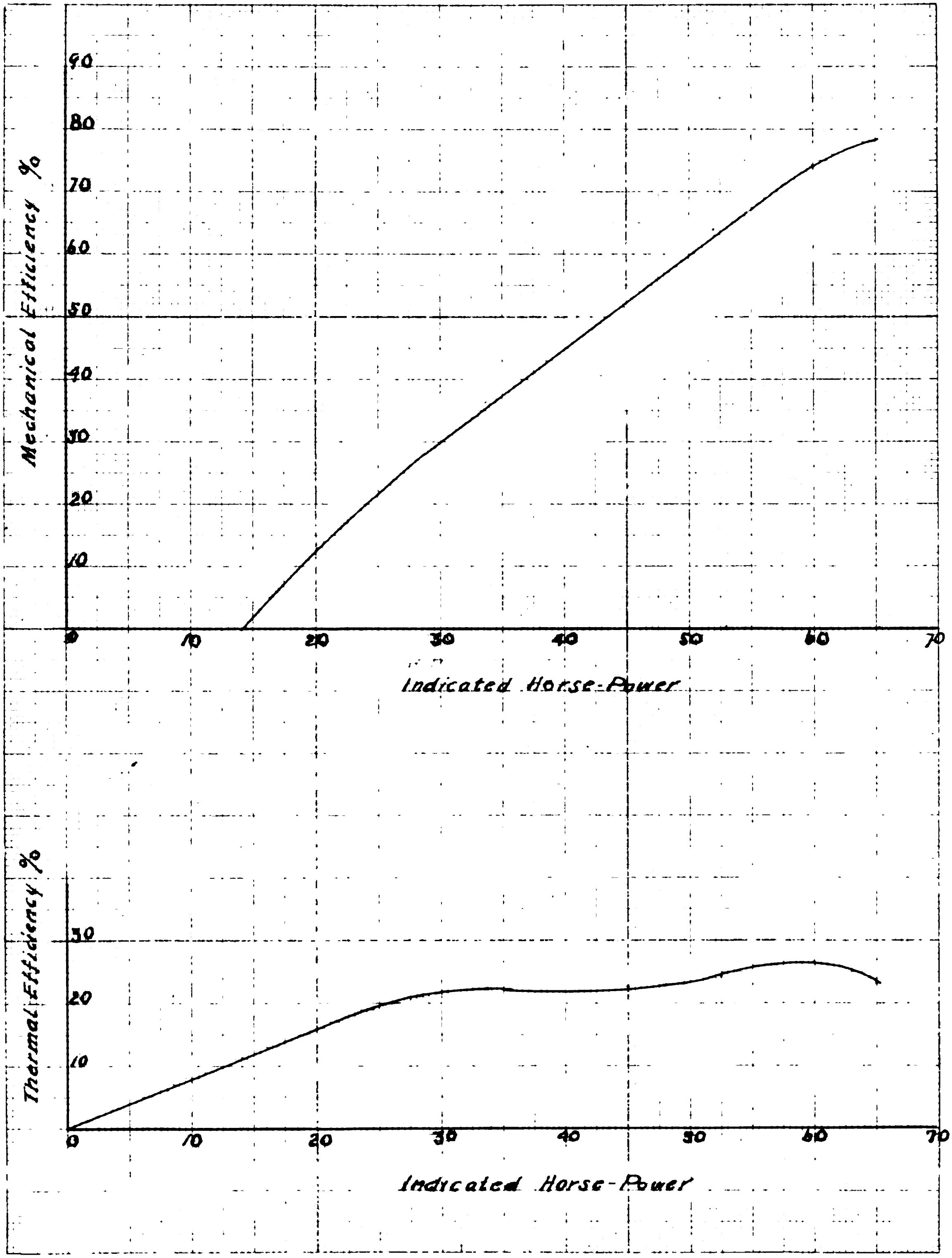
No. of Test,	1	2
Time intervals, minutes,	120	120
Revolutions per minute (mean)	252	251
Explosions " " "	378	376.5
Jacket Water Weight in lbs.	5062	7689
" " " " " per hr.	2531	3845
" " temperature range	47	39
Heat absorbed in B.T.U.	238000	291000
Gas, Cubic feet,	1264	1466
" " " per hour,	632	733
" Temp. Fah. degrees,	944	78
" Cu. ft. standard 60° F. 30"Hg.	1172	1380
" B.T.U. per Cu.ft. standard,	550	550
" total B.T.U. supplied,	643500	750000
M.E.P. 1st Cylinder	8.75	33.36
" 2nd "	20.17	34.16
" 3rd "	6.58	18.10
" total	35.50	95.62

3	4	5	6
120	120	120	120
250	251	247	247
375	376.5	370	370
8098	8484	27861	27341
4049	4242	13935	13670
37.2	42.2	20.8	17.5
308000	357800	580100	478000
: 1986	2070	2255	2707
993	1035	1127	1353
93.3	84	93	83
1825	1930	2070	2555
550	550	550	550
1004000	1065000	1140000	1401000
43.40	46.75	56.63	61.55
40.84	47.93	52.25	59.46
31.12	39.54	45.83	46.16
115.36	134.22	154.71	167.17

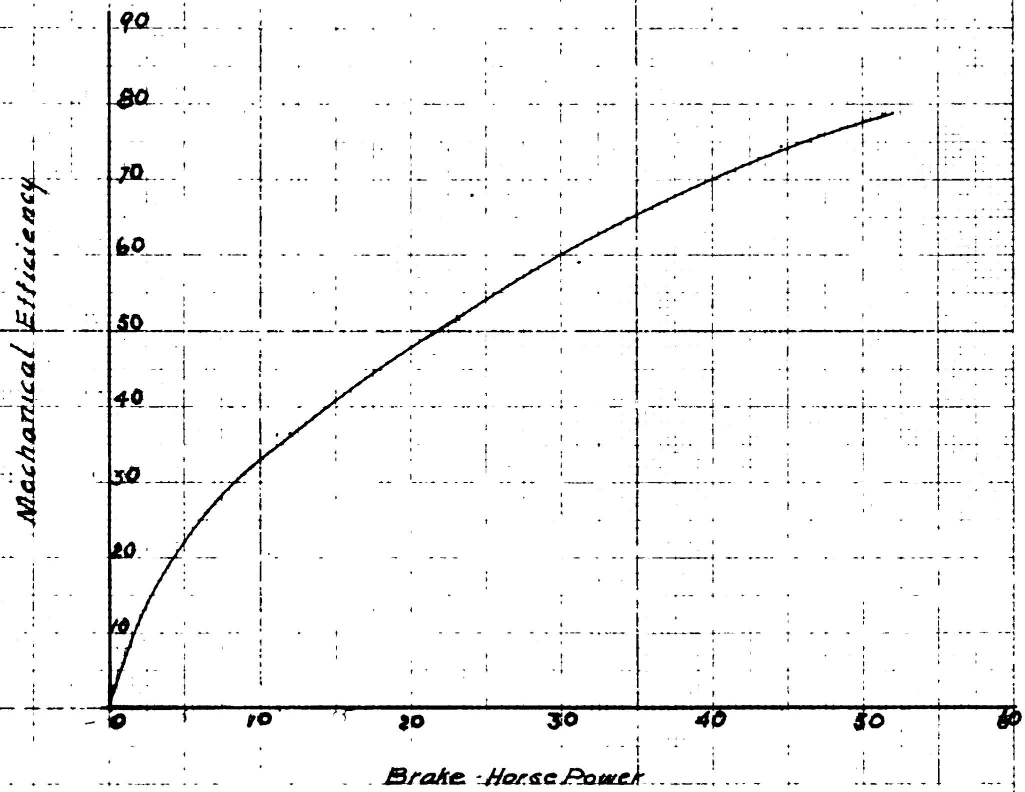
SUMMARY (Continued)

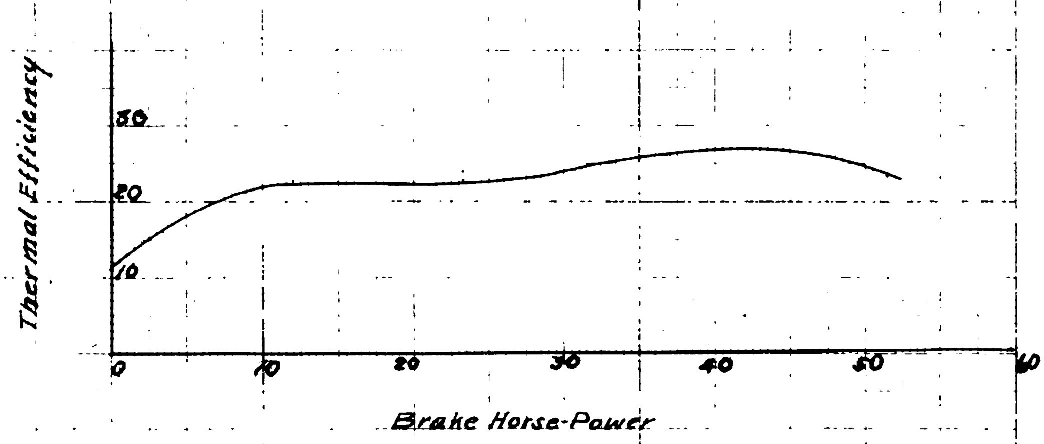
No. of test,(Continued)	1	2
I.H.P. 1st Cylinder,	3.54	13.07
" 2nd "	7.94	13.35
" 3rd "	2.62	7.12
" total	14.1	33.54
Brake horse power,	0	12.2
B.T.U. equivalent to B.H.P./hr.	0	31000
" " " I.H.P./hr.	35900	86150
Mechanical efficiency %	0	36.4
Thermal " "	11.1	22.75
Standard Gas per I.H.P./hr.	41.7	20.1
" " " B.H.P./hr.	0	56.5
Heat absorbed in work %	11.1	22.75
" " " jacket water %,	37	38.4
" " " Exhaust & Rad.	51.9	38.85
Exhaust CO_2 %	5.16	6.5
" O "	8.6	9.1
" CO "	.55	.35

3	4	5	6
16.77	18.43	21.92	23.9
15.58	19.09	20.33	23.13
12.45	15.42	17.75	18.25
44.80	52.94	60	65.28
23.25	31.21	44.6	51.4
59100	79500	113500	130500
114000	134600	152700	165500
51.5	59	74.5	78.7
22.8	24.3	26.8	28.6
20.4	18.25	17.25	18.8
39.2	30.8	23.2	24.8
22.8	24.3	26.8	23.6
30.5	33.6	51	34.2
46.7	42.1	22.2	42.2
5.85	6.2	6.46	7.15
7.76	8.0	8.75	8
.2	.1	trace	.2



Mechanical Efficiency %
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
Indicated Horse-Power
Thermal Efficiency %
30
20
10
0
10
20
30
40
50
60
70
Indicated Horse-Power


Mechanical Efficiency
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
Brake Horse Power


Thermal Efficiency
30
20
10
0
10
20
30
40
50
60
Brake Horse-Power

APPROVED Storm Bull

Professor Steam Engineering

May 28. 1904